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Resource availability for household biogas production in rural China

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ABSTRACT

The objective of this study was to assess biogas production capacity in different regions of China based on climate conditions and substrate availability. The results of our analysis indicated large differences in below-ground temperature and solar energy resources among different regions of China. According to data collected in 2006, slightly more than 1200 million tons of crop residue and manure could be used as substrates for biogas production. We suggest that household biogas technology must be developed according to local conditions.

Contents

1. Introduction

Biogas consists of about 2/3 methane (CH_4), 1/3 carbon dioxide (CO_2), a little hydrogen sulfide (H_2S) and a little hydrogen (H_2), which is produced through the biodegradation of organic materials under anaerobic conditions. Biogas producing materials (substrates) range from animal manure to household, agricultural and industrial wastes [1]. The construction of biogas digesters in rural areas is a key program for the development of renewable energy sources in China [2]. Household biogas construction has developed rapidly in China's rural areas since the 1990s. For example, there were 4.9 million rural households using biogas in 1996. By 2003, the number had increased to 12.3 million households, an annual increase of 14.1%. Annual biogas output increased from 1.59 trillion m^3 in 1996 to 4.61 trillion m^3 in 2003. These amounts were equivalent to 3.8×10^7 J and 9.7×10^7 J. By 2003, annual average biogas output had reached 400 m^3 per household and biogas consumption had risen from 0.33% to 0.72% of total rural energy consumption [3]. This increase in biogas production has not only helped to meet energy demands but also contributed to environmental and economic development in rural areas. In line with its goal of sustainable environmental development, the Chinese government had planned to increase the total number of biogas plants to 50 million by 2010. This required an average

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Table 1
Average ground temperatures at a depth of 1.6 m in different areas of China [6].

Region	Months > 10 °C	Months > 20 °C	Areas
I	12	7–12	Taiwan; Fujian; Guangdong; Southern Guangxi; lower reaches of the Yuanjiang River and Xishuanbanna in Yunnan Province; Northern Fujian; Guangdong and Guangxi; Jiangxi; Southern Hunan; Guizhou; some areas in Southern Yunnan Province
II	12	4–6	Zhejiang; Anhui; Hubei; Jiangsu; Northern Jiangxi and Hubei; Southern Henan Province; some areas in southern Shaanxi Province; East central Sichuan Province; some regions in Yunnan and Guizhou Province
III	7–12	1–3	Tianjin; Beijing; Hebei; most of Shandong; North central Henan; South central Shaanxi; some areas in southern Shanxi Province; Tarim basin Xinjiang
IV	6	0	South central Liaoning; Northern Hebei; South central Shanxi; North central Shaanxi; most of Ningxia; Eastern Gansu; Eastern area of the Gansu Corridor and Yunan

increase of 6 million new biogas plants per year [4]. To successfully develop household biogas production, it is crucial that the temperature regime be suitable and that fermentation be fully achieved [5]. With both of these factors in mind, the potential capacity for biogas production in rural China is evaluated here.

2. Analysis of household biogas resources

The factors that influence the development of household biogas in rural China include (1) climate resources (i.e. the average ground temperature at a depth of 1.6 m, solar energy resources) and (2) biomass resources (i.e. crop residue and manure resources). Climate resources are the main factor for evaluating the fermentation temperature of biogas production. Biomass quantity is the factor which determines whether there is adequate raw material for biogas fermentation.

2.1. Climate resources

2.1.1. Ground temperature

In rural China, most biogas plants are built underground at a depth of about 2 m. Ground temperature is the most important factor affecting the amount and rate of biogas production. The temperature in a 2 m deep biogas plant is appoximately the same as the average ground temperature at a depth of 1.6 m [6]. Generally, the temperature is between 8 °C and 25 °C. The minimum temperature for biogas production is 10 °C; however, biogas production is most rapid when temperatures are above 20 °C [7].

Average ground temperatures at a depth of 1.6 m are shown for different regions of China in Table 1 [6]. The data indicate that ground temperatures are most suitable in regions I and II. In these regions, digesters can produce biogas year round. Biogas production is especially rapid and efficient during the 4–12 months when the ground temperature is above 20 °C. In region III, biogas production is possible for more than half the year; however efficient and rapid biogas production is limited to a timespan of 1–3 months. Cool ground temperatures in region IV severely limit biogas production. Ground temperatures at the depth of 1.6 m are > 10 °C for only 6 months each year. Furthermore, ground temperatures never exceed 20 °C. Therefore, it is inappropriate to develop biogas in region IV.

2.1.2. Solar energy resources

In China, solar-heated livestock buildings or greenhouses are often used in combination with biogas digesters. The solar heat increases the temperature within the digester. Therefore, it is important to consider solar radiation and total sunshine hours for each region [8]. Solar radiation is the total frequency spectrum of electromagnetic radiation produced by the sun.

The distribution of China's solar energy resources is shown in Table 2. Solar radiation is abundant in regions I and II. In these areas, annual total solar radiation is > 5400 MJ m^{-2} yr^{-1} and the annual number of sunshine hours is 2800–3300 h. In region III, annual total solar radiation ranges from 4200 to 5400 MJ m^{-2} yr^{-1} and the annual number of sunshine hours ranges from 2200 to 3000 h. In region IV, the annual total solar radiation is below 4200 MJ m^{-2} yr^{-1} and the annual number sunshine hours ranges from 1400 to 2200 h, making these areas poor in solar energy.

2.2. Biomass resources

This analysis contains the estimation of biomass quantities potentially available in two categories: crop residue and manure resources.

2.2.1. Agricultural residues

Crop residue amounts depend on the output of farm crops. After harvest, a portion of the crop residue can be collected for biogas production. Rice, wheat, corn, beans, potatoes, cotton and oil-seed crops are the main crops in China. Analysis in this paper is limited to rice straw, wheat straw, corn cobs, corn stalks, soybean stalks, sweet potato stalks, cotton stalks, and oil-seed crop stalks. Crop residue amounts were estimated from crop yield and residue factors (the residue factor is sometimes referred to as shoot to grain ratio) [10].

Yields for the major crops in China in 2006 are shown in Table 3.

Data in Table 4 indicate that a total of 725.09 million tons of crop residue was produced during 2006. Corn residue accounted for 40% of the total crop residue (Tables 3 and 4). Areas with the largest amount of corn residue were the North China Plain (Hebei Province and the Inner Mongolia Autonomous Region), northeastern China (Lioning, Jilin, and Heilongjiang Provinces), eastern China (parts of Shandong Province), and south central China (parts of Henan Province). The second largest amount of crop residue was rice straw, which accounted for 25% of the total crop residue produced in China during 2006. Areas with large amounts of rice straw included south central China (Hunan, Hubei, Guangdong and Guangxi Provinces), eastern China (Jiangsu, Jiangxi, Zhejiang and Anhui Provinces) and southwest China (Sichuan). Wheat residue accounted for 14% of the total crop residue. Areas with large amounts of wheat straw included eastern China (Shandong, Jiangsu and Anhui Provinces), south central China (Henan Province) and northern China (Hebei Province). Oil seed crops accounted for 8% of total crop residue production while tubers accounted for 7%, beans accounted for 4%, and cotton accounted for 3%.

2.2.2. Manure resources

Animal manure is an important input in biogas production. Most animal manure in China comes from (1) swine, (2) cattle and buffaloes, and (3) sheep and goats. Potential manure amounts

Table 2
Spatial distribution of solar energy resources in China [9].

Region	Annual sunshine hours	Total annual solar radiation ($MJ\ m^{-2}\ yr^{-1}$)	Areas
I	2800–3300	≥6700	Northern Ningxia; Northern Gansu; Southeastern Xinjiang; Western Qinghai; Western Tibet
II	3000–3200	5400–6700	Northern Hebei; Northern Shanxi; Southern Inner Mongolia and Ningxia; Central Gansu; Southern Xinjiang; Southeast Tibet; Eastern Qinghai
III	2200–3000	4200–5400	Shandong; Henan; Southeast Hebei; Southern shanxi; Northern Xinjiang; Jilin; Liaoning; Yunnan; Northern Shannxi; Southeast Gansu; Southern Fujian; North Jiangsu and Anhui; Beijing
IV	1400–2200	< 4200	Hubei; Hunan; Jiangxi; Zhejiang; Guanxi; Northern Guangdong; South Shaanxi, Jiangxi and Anhui; Heilongjiang

Table 3
The yield of major crops in China in 2006 (Units: 10^4 t) [11].

Regions		Rice	Wheat	Corn	Beans	Potatoes	Cotton	Oil-seed crops
North China Plain	Beijing	0.43	30.01	72.91	2.68	2.58	0.2239	2.1656
	Tianjin	12.41	52.04	75.75	2.66	0.35	10.8727	1.2011
	Hebei	53.23	1149.54	1280.52	52.91	112.05	62.8	150.2957
	Shanxi	0.83	252.61	647.61	40.25	61.67	11.7808	19.1852
	Inner mongolia	65.63	145.71	1091.69	143.15	180.63	0.2247	116.8428
Northeast China	Liaoning	427.6	6.5	1138.7	36.1	48.7	0.2096	38.1245
	Jilin	493	3.0181	1984	150	39	0.2802	58.3666
	Heilongjiang	1205.5	93	1223	652	82.2	0	63.0855
East China	Shanghai	89.7	11.34	2.68	3.1	1	0.1999	5.3062
	Jiangsu	1792.72	817.82	197.2	87.25	53.36	38.13786	218.1805
	Zhejiang	706.62	24.54	27.98	48.47	62.03	2.3936	47.3537
	Anhui	1307	966.8	297.9	132.2	124.43	40.82463	261.6474
	Fujian	508.84	1.85	13.07	24.44	151.15		26.9385
	Jiangxi	1766.9	2.04	6.09	26.82	51.68	9.5015	77.9766
	Shandong	106.61	1889.79	1761.28	65.61	209.14	102.31	358.2387
South central China	Henan	426.69	2822.69	1445.11	76.43	196.36	83	479.9918
	Hubei	1524.85	243.2	208.25	62.45	154.2	44.86198	279.7517
	Hu'nan	2319.7	13.1	137.2	60	166.5	24.8	149.4105
	Guangdong	1104.3	1.7169	62.87315	24.96554	189.0596	0	77.5671
	Guangxi	1162.6	1.8	198	39.5	59.6	0.1396	64.1541
	Hainan	144.386	0	5.604	2.159	33.362	0	8.96211
Southwest China	Chongqing	381.25	75.44	206.1	35.39	202.21		40.3265
	Sichuan	1335.9	439	511.2	98.3	460.6	1.5726	217.266
	Guizhou	447.2	74.5	338.95	38.4	212.03	0.0526	89.4803
	Yunnan	651.17	110.13	452.06	68.4	204.91		39.0078
	Tibet	0.59	26.53	1.7	3.16	0.71	0	5.459761
Northwest China	Shaanxi	86.3	415.7	443.5	48.01	80.14	8.7042	44.3565
	Gansu	4.02	260.7	218.6	39.46	187.95	12.7509	48.994
	Qinghai	0	38.51	0.75	10.2	30.89	0	26.5
	Ningxia	70.94	75.72	121.54	5.22	32.46		10.4334
	Xinjiang	60.27	401.39	376.37	24.78	15.16	218.8821	32.821
	Total	18257.186	10446.735	14548.187	2104.464	3406.112	674.58	3059.391

Table 4
Output of the major farm crops and the total quantity of crop residues in rural China in 2006.

Crop	Output (× 10^6 t)	Residue factor [12]	Crop residue (× 10^6 t)	Percent of total (%)
Rice	182.57	1	182.57	25.2
Wheat	104.47	1	104.47	14.4
Corn	145.48	2	290.96	40.1
Beans	21.05	1.5	31.58	4.4
Potatoes	34.06	1	34.06	4.7
Cotton	6.75	3	20.25	2.8
Oil-seed crops	30.60	2	61.20	8.4
Total	524.98		725.09	100

were estimated by multiplying the total number of animals by the expected annual rate of manure production per animal (manure dry weight per head of livestock per year) [13].

Data regarding livestock populations in different regions of China are shown in Table 5. A total of 478.28 million tons of manure was produced in China during 2006 (Table 6). Swine manure accounted for 54% of the total manure production (Tables 5 and 6). Swine manure production was the largest in the North China Plain (Hebei Province), eastern China (Shandong Province), south central China (Henan and Hunan Provinces), and southwestern China (Sichuan Province). Cattle and buffalo manure was the second largest amount, accounting for 32% of total manure production. The amount of cattle and buffalo manure was the largest in the North China Plain (Hebei Province), eastern China (Shandong Province), south central China (Hunan and Guangxi Province), and southwestern China (Sichuan Province). Sheep and goat manure, which amounts to 13.9% of the total manure production, was the largest in amount in the North China Plain (Hebei Province and the Inner Mongolia Autonomous Region), eastern China (Shandong Province), south central China (Henan Province) and northwest China (Xinjiang Uyghur Autonomous Region).

Table 5
Livestock numbers in China in 2006 (Units: 10 000 head)[11].

Region		Cattle and buffaloes	Swine	Sheep and goats
North China Plain	Beijing	23.39	567.17	103.24
	Tianjin	39.25	765.61	73.3
	Hebei	829.85	7718.05	2425.52
	Shanxi	231.02	1147.95	1140.71
	Inner mongolia	630.88	1804.69	5594.44
Northeast China	Liaoning	370.7	3885.55	818.4539
	Jilin	600	1990.9	450
	Heilongjiang	542.28	2915.87	996.75
East China	Shanghai	5.58	380.44	28.26
	Jiangsu	64.3	4804.28	1186.5
	Zhejiang	31.37	3019.69	198.32
	Anhui	308.45	4165.33	819.8
	Fujian	100.21	3242.23	132.34
	Jiangxi	356.22	3858.43	92.12
	Shandong	832.72	7420.14	2918.1
South central China	Henan	1496.2	10636.47	4308.52
	Hubei	367.64	5873.2	319.3
	Hu'nan	583.4206	10622.21	694.08
	Guangdong	363.2093	5874.29	37.6717
	Guangxi	726.5673	5622.81	263.6812
	Hainan	138.61	877.67	92.95
Southwest China	Chongqing	164.94	3576.59	348.3
	Sichuan	1147.6958	13228.41	1590.45
	Guizhou	814.6	3721.97	464.1
	Yunnan	782.4	5520.71	937.5
	Tibet	650.99	50.28	1702.84
Northwest China	Shaanxi	311.31	1601.2	1000.54
	Gansu	431.03	1453.57	1573.4
	Qinghai	389.41	233.99	1780.63
	Ningxia	107.1	276.73	445.3
	Xinjiang	502.86	634.7	4359.5
Tatol		13944.203	117491.103	36896.616

Table 6
Estimated animal manure production in China during 2006.

Livestock	Number of animals ($\times 10^6$ head)	Annual dry manure production per animal (ton/head)[13]	Manure dry weight ($\times 10^6$ t)	Percent of total production (%)
Cattle and Buffaloes	139.44	1.1	153.38	32.1
Pigs	1174.91	0.22	258.48	54.0
Sheep and Goats	368.97	0.18	66.42	13.9
Total	1683.32		478.28	100

3. Conclusions and recommendations

3.1. Conclusions

The resources that influence the development of household biogas production systems in rural China were analyzed in this paper. The spatial distribution of climatic resources such as ground temperature and solar energy is uneven. Temperatures are too cool for the successful development of household biogas production systems in south central Liaoning, northern Hebei, south central Shanxi, north central Shaanxi, most of Ningxia, eastern Gansu, the eastern part of the Gansu corridor, and Yunnan Province. Solar radiation is insufficient for biogas production systems in Hubei; Hunan; Jiangxi; Zhejiang; Guanxi; northern Guangdong; southern Shaanxi, Jiangxi, Anhui; and Heilongjiang Provinces. Despite limitations in these areas, the climate in many other parts of China is favorable for the development of household biogas systems. It is estimated that 1200 million tons of crop residue and manure were produced in China during 2006. Raw biomass which is needed for fermentation in biogas digesters is especially abundant in Hebei, Henan, Shandong, and Sichuan Provinces.

3.2. Recommendations

Climate resources and biomass resources are two important factors that influence the development of household biogas in rural China. Winter (November–March) conditions in northern China are unsuitable for biogas production because the daily mean temperature is lower than 10 °C. In these colder regions, solar-heated livestock buildings or greenhouses are used in combination with biogas digesters. However, Qinghai-Tibet Alpine Region is poor in solar energy, which is not suitable to develop household biogas in winter.

These regions have a shortage of raw materials of rural biogas from planting and breeding. For example, with the development of the urbanization and the large-scale development of the intensive breeding industry, the rural disperse culture is decreasing day by day. As a result, these areas are unsuitable for developing household biogas where the raw materials are insufficient. Development of household biogas in China is affected not only by climate resources and biomass resources in different regions, but also by the level of rural social economy and other factors. Choosing biogas as an energy source or not is closely related to the consumer incomes and energy situation of the consumer's location. In some poor areas, farmers cannot afford the funds of digester construction. In areas which are rich in geothermal energy, solar, wind, and micro-hydro resources, people should not focus on biogas development only. We suggest that household biogas technology should be adapted according to local conditions.

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